

Comparison of Aircraft Observations with Surface Observations from R/V POINT SUR

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1. Introduction

As the Naval Meteorology and Oceanography (METOC) community undergoes transformation to incorporate the latest scientific and technological advances, the idea of Rapid Environmental Assessment (REA) is a critical part of the *Naval Oceanography Program Operation Concept* and its requirement for timely environmental characterization of the battlespace (2002). A key component of REA is the use of aircraft to rapidly survey the area in an effort to augment the traditionally remotely-sensed data, such as that from satellites, and in-situ observational data, such as ship-collected data. While the aircraft does provide a unique opportunity to gather in-situ atmospheric data and remotely-sensed surface data, the characterization of biases and error sources of those aircraft-collected data as compared to those of the other data are of concern.

The Winter 2003 Operational Oceanography cruise provided a unique opportunity to compare data collected from both ship and aircraft. The Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) provided two, four-hour, data collection overflights during the R/V POINT SUR's eight-day cruise. In this paper, two areas of comparison are explored: first, the difference in bulk method surface fluxes derived from aircraft and ship measurements, and, second, the characterization of temporal and spatial variability differences in wind measurements between platforms. Both areas are of great importance to the characterization of the battlespace. Specifically, flux measurements impact the ability to characterize the evaporative duct height and its effects on radar propagation, while the wind data is crucial to amphibious operations. As such, characterizing and understanding such differences in both cases are critical to the REA concept.

2. Data and Methods

Meteorological and oceanographic observational data were collected during the oceanographic cruise on the Research Vessel POINT SUR during the period of 27 January 2003 to 3 February 2003. Additionally, in-situ meteorological and remotely-sensed surface oceanographic data were collected on 27 January 2003 and 1 February 2003 by the UV-18A “Twin Otter” aircraft from CIRPAS. Data used in this study consisted of wind direction, wind speed, position, time, air temperature, relative humidity, pressure, and sea surface temperature. Ship-collected measurements were collected approximately every 54 seconds using POINT SUR’s Science Data Acquisition System and are referred to as the SAIL data. The aircraft measurements were recorded digitally by the “Twin Otter” every second and provided to the Naval Postgraduate School by CIRPAS. The POINT SUR’s area of study covered a coastal box off of Central California which encompassed California Cooperative Oceanic Fisheries Investigations (CalCOFI) line 67 to station 67-70, alongshore to station 77-70, inshore along CalCOFI line 77 to Port San Luis, and finally, several inshore CalCOFI hydrography lines within the outer box as the POINT SUR returned north to Monterey Bay. See figure 1. The “Twin Otter’s” area of study covered mainly the same inshore CalCOFI lines covered by the POINT SUR within the outer box. See figure 2.

A. Bulk Method Surface Flux Comparison

To accomplish the first task of comparing surface fluxes based on the bulk method using measurements from both the aircraft and the ship, data from both sources had to be found that was both temporally and spatially coincident. Due to the differences in speed between the aircraft and the ship, the only data that met both the spatial and temporal

criteria occurred within a fifteen-minute window on each flight day, 27 January 2003 and 1 February 2003. See figures 3 and 4 respectively. The ship data, which included wind speed, air temperature, relative humidity, sea surface temperature, and pressure, were averaged over the fifteen-minute window to obtain entering arguments for the Matlab bulk method surface flux program, `sfcfluxoc3570`, written by Guest (1997). The height of the shipboard measurements was taken to be constant at fourteen meters. Due to the magnitude of the altitude excursions of the plane, as much as 400 meters in some cases, averaging the aircraft data made little sense. Instead, values for air temperature, relative humidity, sea surface temperature, and pressure were taken at the minimum altitude in the time series and the wind speed was averaged for a 30 second period during the lowest 10 meters of the flight. Time series of these parameters comparing the aircraft and ship data for both days can be seen in figures 5 and 6. Observation heights for both the aircraft and ship measurements as well as wind speed comparisons can be seen in figures 7 and 8.

The surface fluxes were calculated using a bulk method formulation from Smith (1990) in a Matlab program written by Guest (1997) using an iterative method to ensure convergence of the results. While formulations for calculating the surface fluxes using the bulk method may vary, the objective was to determine the consistency of the results between aircraft and ship data. For purposes of comparison, input parameters from both the aircraft and the ship were reduced to their ten-meter equivalents. In the Results and Discussion section, differences, the source of those differences, and possible sources of error will be discussed.

B. Temporal/Spatial Variability of Measured Winds

Past cruises have shown that wind data collected from the ship shows a weakening of the winds as the ship moves inshore. However, because of the slow movement of the ship, it becomes hard to separate temporal variability from spatial variability. With wind data from the aircraft, data may be collected more synoptically, removing the temporal variability and providing a better look at spatial variability. To accomplish this, the total measured wind fields were plotted for the aircraft and the ship for 27 January 2003 and 1 February 2003. See figures 9 through 12. Due to the high frequency of observations and the differing speeds, the aircraft data was reduced to one wind speed and wind direction observation per minute and the ship data was reduced to one wind speed and wind direction observation per fifteen minutes. Bin averaging over these windows was not done to prevent masking of any spatial variability. Finally, using the Matlab program, `windvector`, written by Guest (2003), the wind direction using the meteorological convention (from) and scaled wind speed were plotted for the plane and ship tracks respectively. See figures 9 and 10. Differences in the measured fields will be discussed in the following section.

3. Results and Discussion

A. Surface Flux Comparison

The surface fluxes calculated using the bulk method formulations from Smith (1990) for 27 January 2003 and 1 February 2003 are presented in Table 1. On 27 January, it can be seen that the aircraft's level of observation was approximately six meters higher than that of the ship. Air temperature, sea surface temperature, and pressure differences were

both less than five percent of the lower value, while the relative humidity and wind speed differences were as much as 30 percent of the lower value, with an especially large difference in relative humidity. To ensure a valid comparison, the 10-meter values are also presented in the table. Again, differences in the 10-meter ambient air temperature and 10-meter potential temperature remain small, but the 10-meter winds and 10-meter specific humidity show larger differences as would be expected from the input parameters. The ultimate result of these differences is a marked difference between the fluxes derived from the aircraft and plane data. According to the ship data, total heat flux is almost negligible as the sensible heat flux and latent heat flux are almost balanced. The aircraft data, however, suggest a large positive total heat flux as the latent heat flux is five times greater and of opposite sign from the sensible heat flux. Such differences would have profound effects on evaluation of the evaporative duct and associated radar propagation tendencies. The other marked difference found was that of the wind stress, τ . The ship was found to have a wind stress almost three times larger than that of the wind stress based on the aircraft data. When comparing the 10-meter winds, we see that the aircraft measured winds show a 1.5 meter per second difference lower than that of the ship. Given that the wind stress is proportional to the square of the 10-meter wind and the drag coefficient for the plane was twenty percent smaller than that for the ship, the resulting wind stress difference can be numerically explained.

The differences seen in the input parameters are likely caused by two main sources of error. First, the large differences in relative humidity from the plane explain part of the total heat flux discrepancy. When compared with the upper air sounding for 27 January 2003 (Fig. 13), the relative humidity measured by the ship appears to be

biased to the high side, while the plane may be biased to the low side. Observations taken prior to launching the Rawinsonde show a relative humidity of approximately 78%, almost half way between the aircraft and ship measurements. This implies that calibration of both the aircraft and ship humidity sensors may be suspect. The second source of error likely lies in the wind measurements from one or both platforms. Because both measured winds were relatively light, so any error in magnitude could potentially constitute a relatively large percentage error in actual wind speed or the 10-meter wind speed. Again, since wind stress is based on the square of the 10-meter wind speed, any error is greatly increased in the calculation of wind stress. Also suspect is the fact that the aircraft-measured wind speed, although higher, was less than that of the ship-measured wind speed. While winds are expected to increase as one rises to the top of the boundary layer, the upper air sounding launched as the plane left station over the ship shows light and variable winds below 100 meters. See figure 13. This implies that the one or both of the measurements were erroneous or that the variability of wind in the vertical could account for the discrepancy. Without further information, either is equally likely.

The same process was repeated for the flight on 1 February 2003. The plane's minimum altitude during its time window over the ship, however, was approximately 80 meters. This placed the plane and its measurements out of the surface layer, a requirement for the Smith (1990) formulation for surface fluxes. While 10-meter values for temperature and potential temperature compare well, the marked difference in 10-meter wind speed results in a large discrepancy in derived surface fluxes. The data are presented in Table 1. Had the plane measured surface fluxes directly, surface layer

scaling could be used for comparison with the ship-derived fluxes, but no such data were available.

B. Temporal/Spatial Variability of Measured Winds

Comparison of the ship-measured and aircraft-measured wind fields for 27 January (Fig. 9) shows relatively good agreement in magnitude and a clockwise spiral with increasing height consistent with Ekman theory as described in Holton (1992). Within Monterey Bay, however, ship and aircraft measurements show marked differences in magnitude, as much as 100 %, and directional differences as large as 180 degrees. Ship measurements near shore were taken as much as four hours prior to the aircraft measurements. This shows that the ship measurements taken as the ship headed west out of Monterey Bay included not only spatial variability, but also temporal variability. Another feature captured by the aircraft data due to its rapid spatial coverage is the change in wind direction in the northwest wind as it becomes more westerly when encountering the Santa Cruz mountains and enters Monterey Bay, a feature not captured by the single ship track.

The comparison of ship and aircraft measured wind fields for 1 February 2003 (Fig. 10) also shows good agreement in magnitude and a clockwise spiral with increasing height consistent with Ekman theory as described in Holton (1992). Note that the ship winds are relatively scaled on a maximum wind speed half that of the plane's maximum wind speed. Due to the stronger winds and a deeper boundary layer, the turning of the winds with height is less than that seen on 27 January. The ship track for that day does not approach the shore closely, nor does the geography present any sheltered bays as seen

on 27 January, so agreement is consistent overall. Again, the coastal winds measured by the aircraft show the winds roughly following the coastal terrain features. By looking at both the data collected on 27 January and 1 February, the logical conclusion is that the aircraft can achieve a more synoptic evaluation of the wind field, thereby capturing the spatial variability with little contamination by temporal variability as seen in the ship measurements.

4. Recommendations for Future Studies

While the data collected during this cruise was informative, a study designed to collect a significant amount of aircraft and ship data that is both spatially and temporally coincident would be necessary to quantitatively describe any biases. Additionally, such a study would also require careful calibration of both aircraft and ship instruments prior to the study. Any further efforts to compare surface fluxes, or applications based on surface fluxes such as radar propagation, would require the aircraft to fly at a consistently low altitude to ensure the aircraft was in the surface layer and altitude excursions are kept to a minimum. Statistical evaluations of the aircraft data collected with each specific instrument would be required before proper weighting and error functions could be assigned for use in model analysis fields.

5. Conclusions

It has been shown that the combination of both aircraft and ship data has the potential to separate temporal and spatial variability of observations. While further study is necessary, the ability of aircraft to rapidly collect environmental data over a large area is

well accepted. However, as shown by the comparison of surfaces fluxes calculated on 27 January 2003 and the inability to make valid comparisons using the 1 February 2003 data, the proper data collection plan is crucial to validity of the data collected. With respect to Rapid Environmental Assessment, shipboard and aircraft measurements are but two, although important and powerful, methods among a myriad of tools at the disposal of the Department of Defense.

References

Guest, P., sfcfluxoc3570.m, 1997. Matlab program.

Guest, P., windvector.m, 2003. Matlab program.

Holton, J. R., *An Introduction to Dynamic Meteorology*. Academic Press, San Diego, 1992.

Naval Oceanography Program Operational Concept, March 2002, 48 pp.

Smith, S.D. 1988: Coefficients of sea surface wind stress, heat flux, and wind profiles as a function of wind speed and temperature. *J. Geophys. Res*, 93, 15,467-15,472.

OC3570 Cruise Ship Track 27 Jan – 3 Feb 2003

OC3570 Ship and Plane Tracks

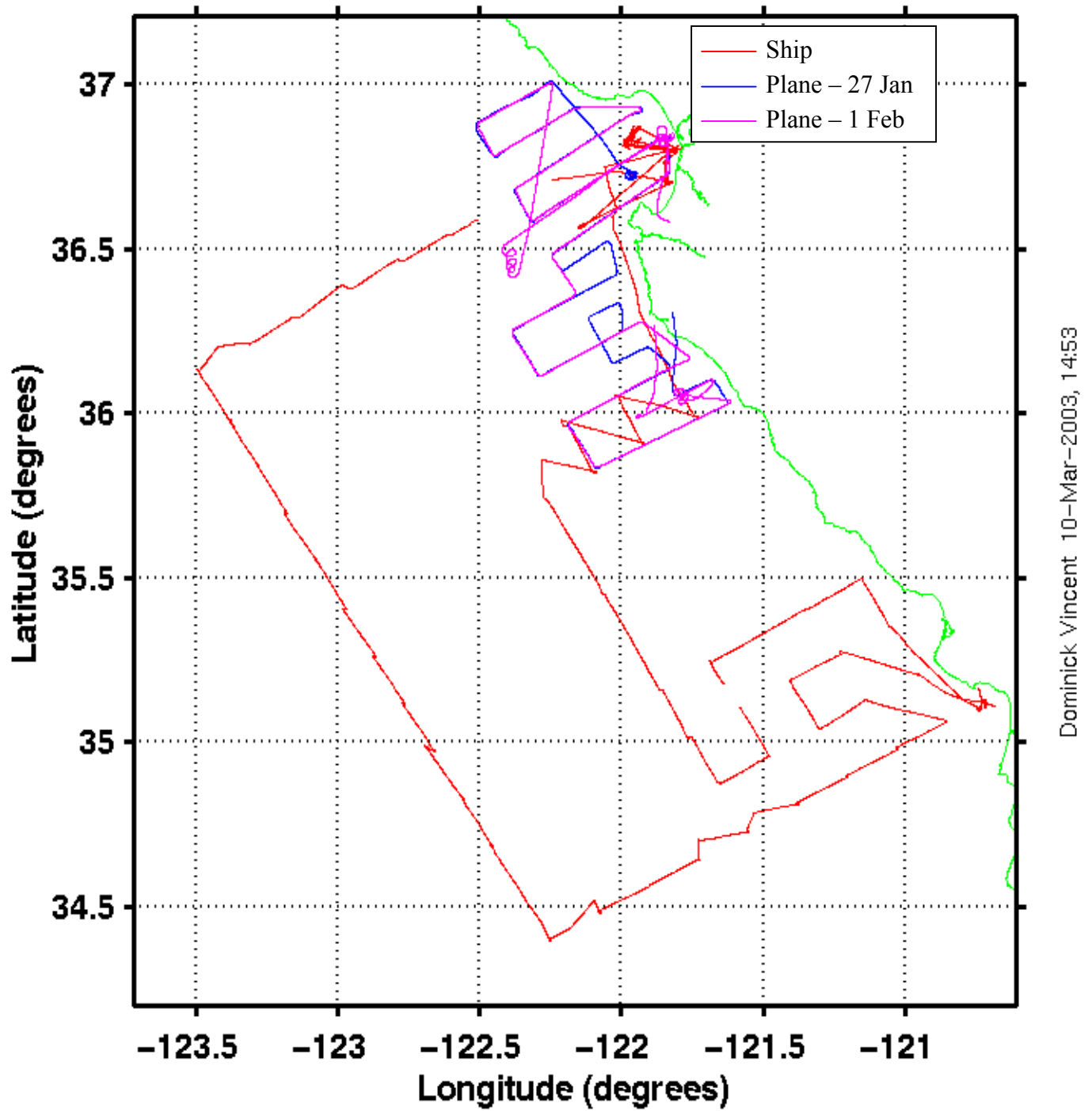


Figure 1

OC3570 Cruise Plane Tracks - 27 Jan & 1 Feb 2003

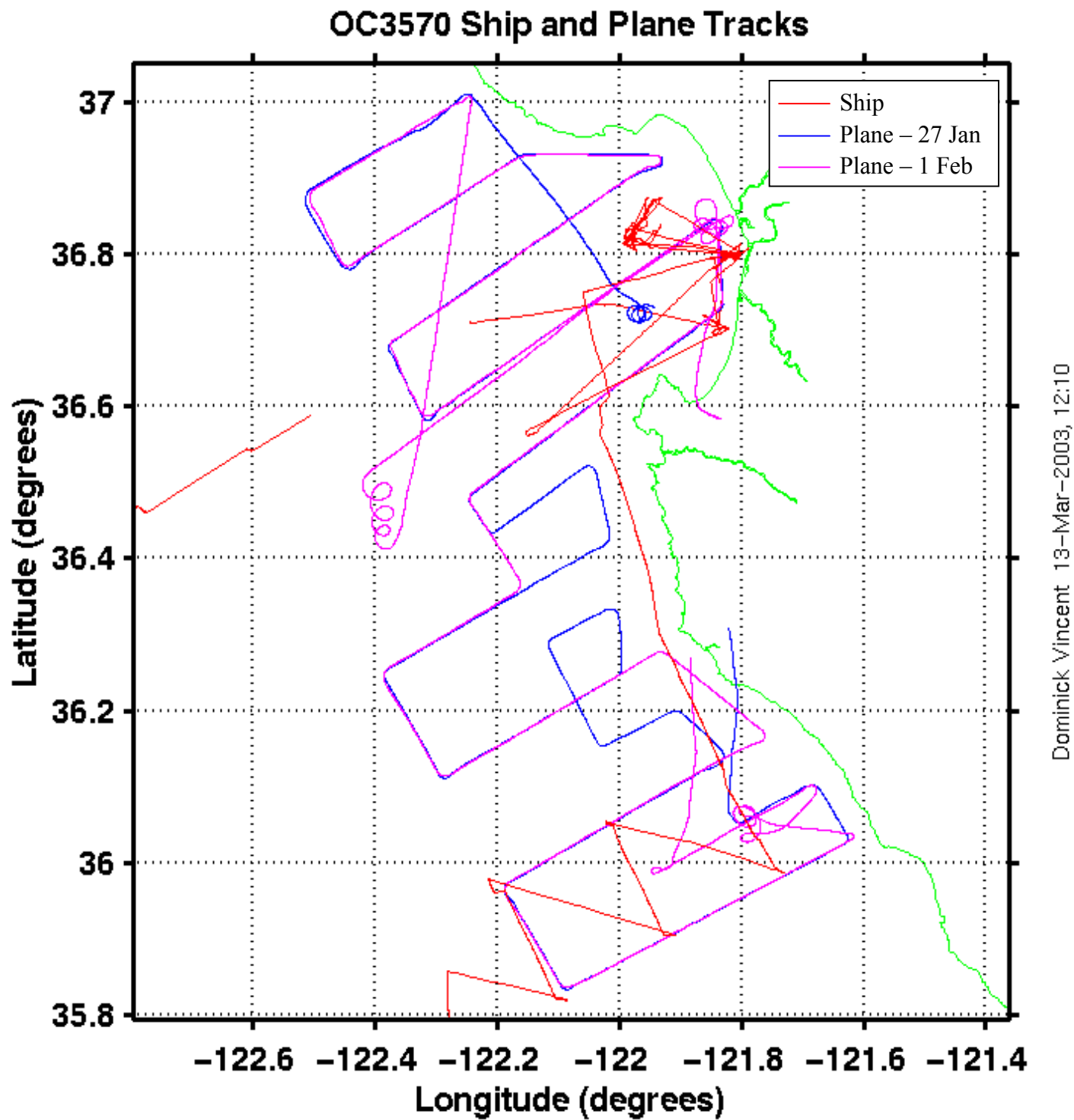


Figure 2

27 January 2003 Coincident Ship and Plane Tracks - Zoom

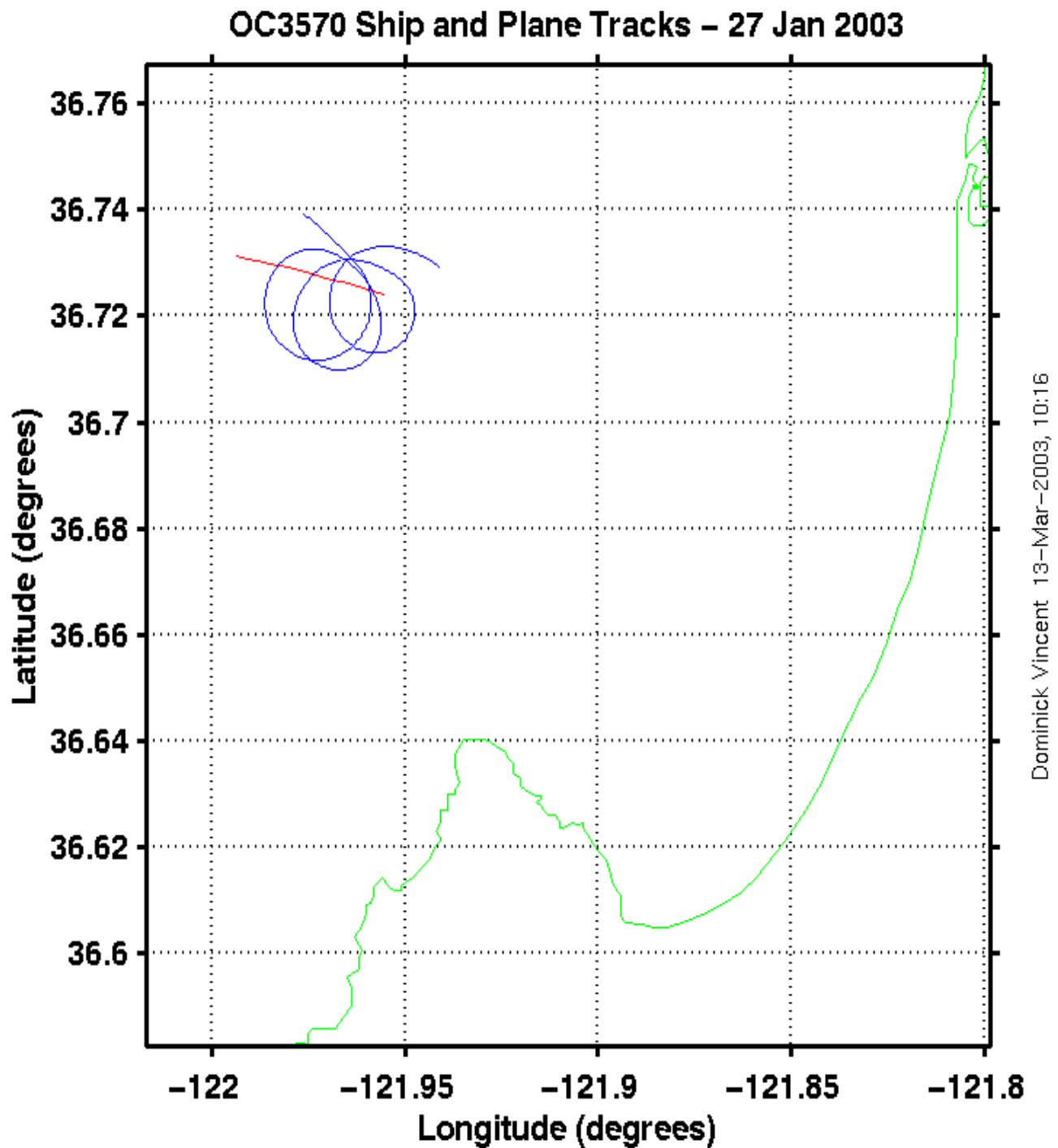


Figure 3

1 February 2003 Coincident Ship and Plane Tracks - Zoom

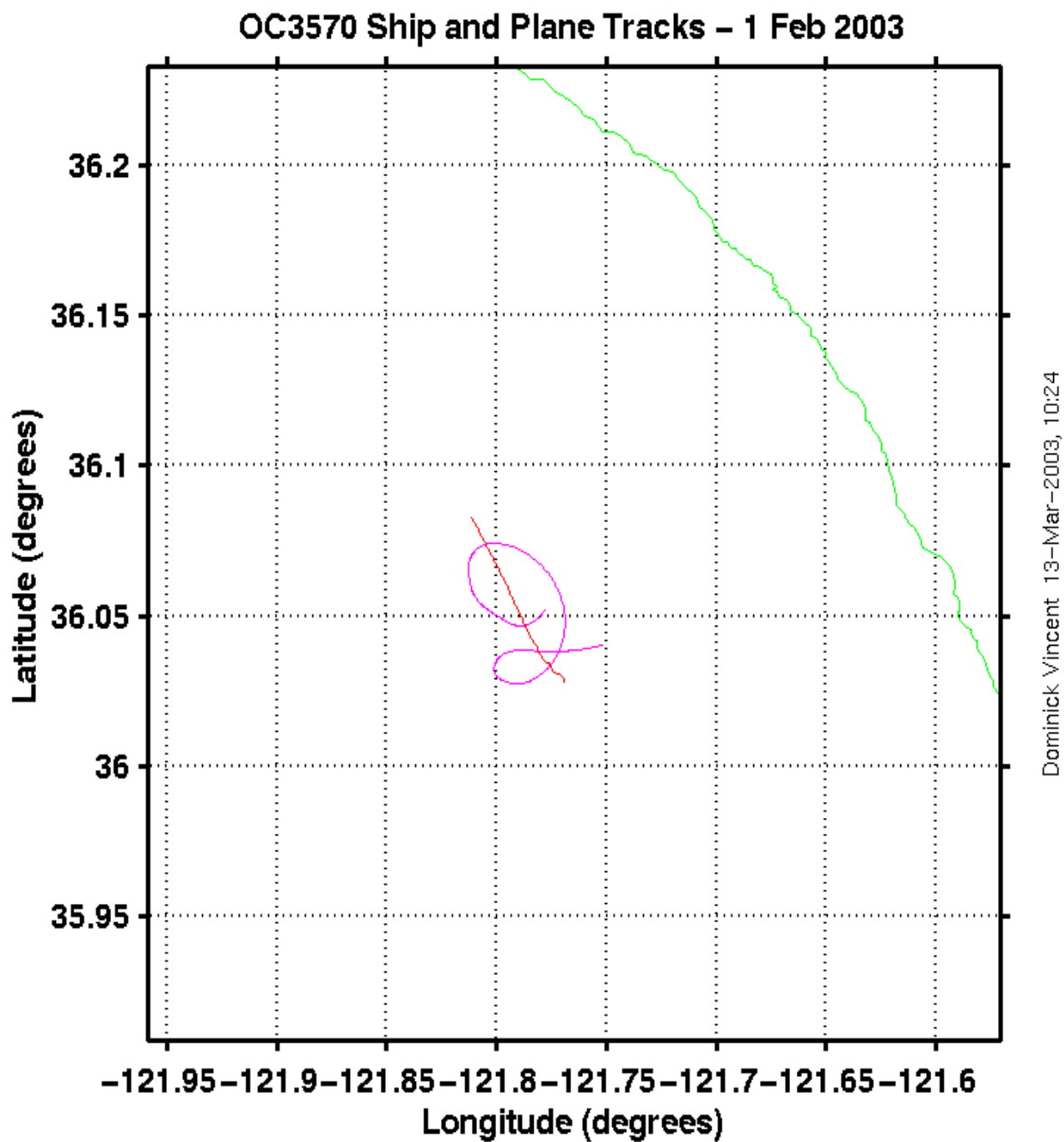


Figure 4

27 January 2003 Ship and Plane Measurement Comparison

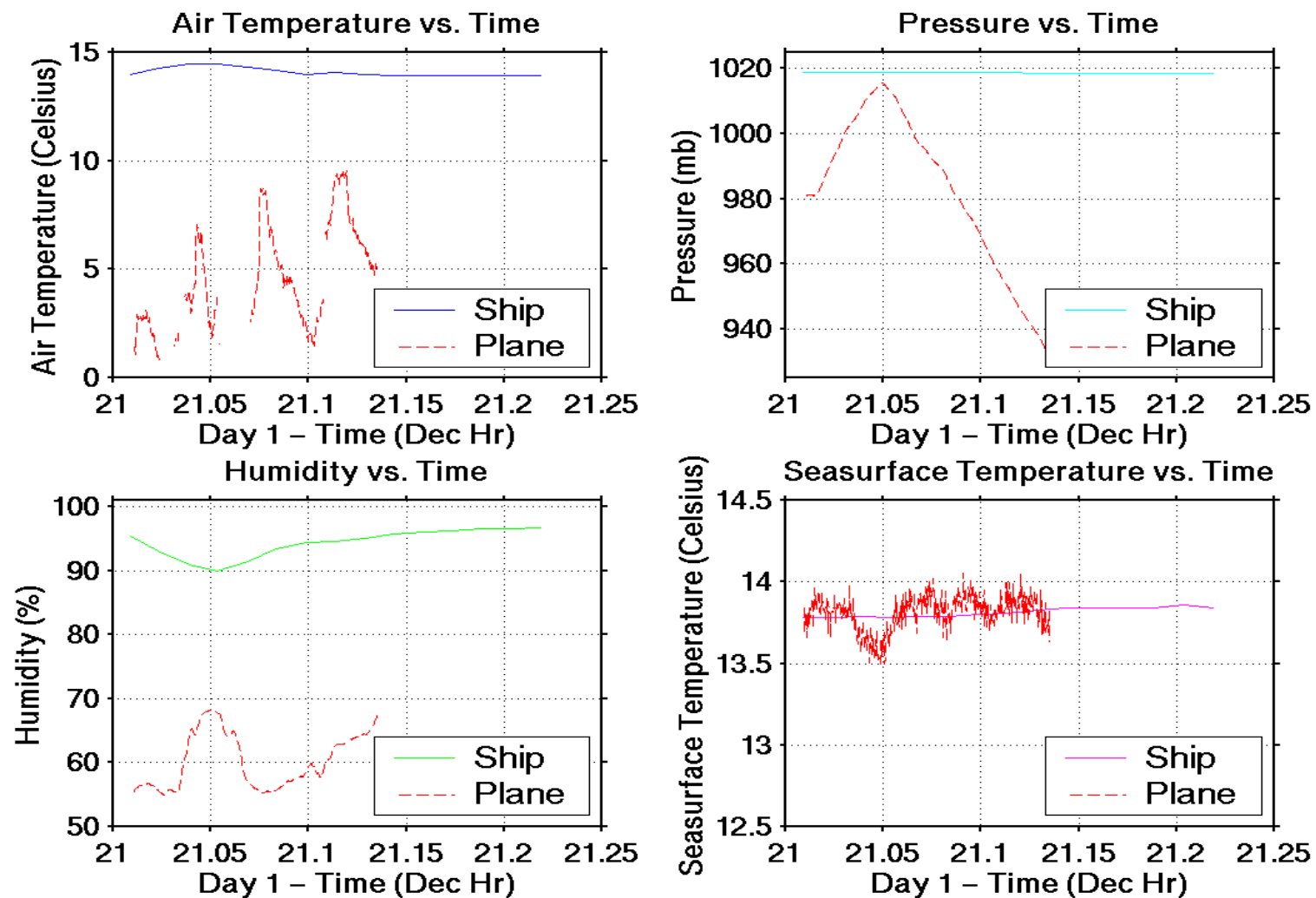


Figure 5

1 February 2003 Ship and Plane Measurement Comparison

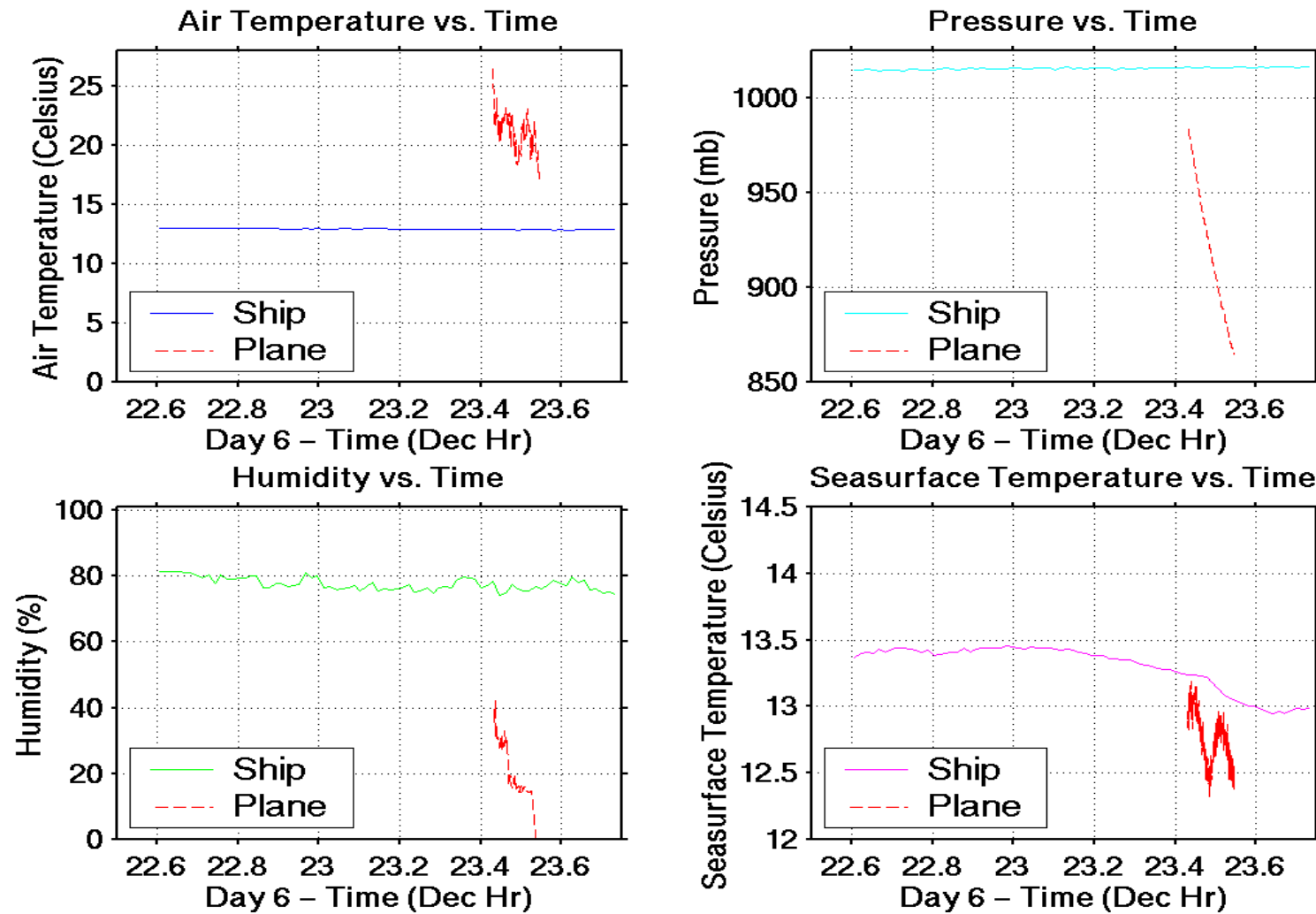


Figure 6

27 January 2003 Ship and Plane Measurement Height

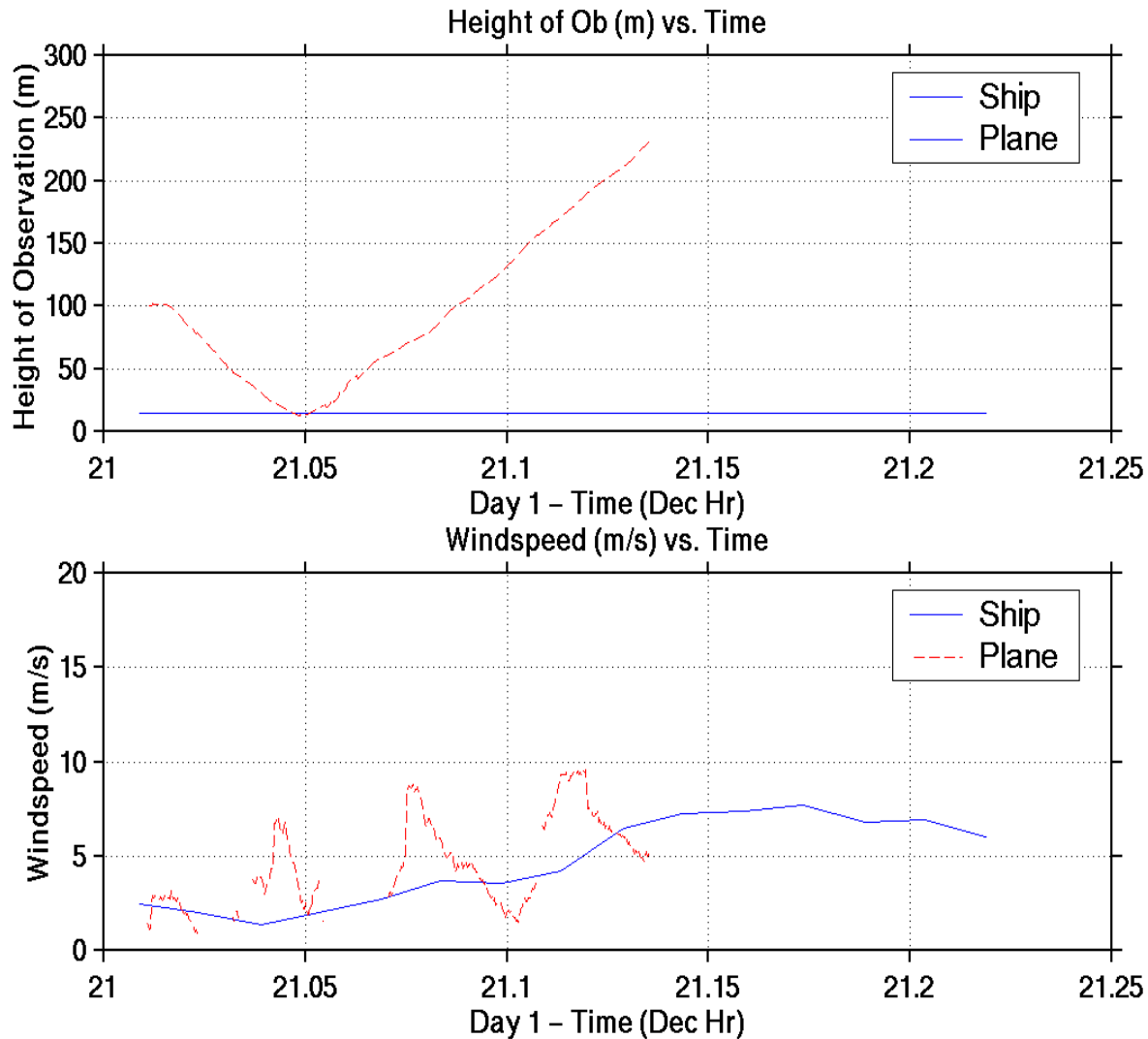


Figure 7

1 February 2003 Ship and Plane Measurement Height

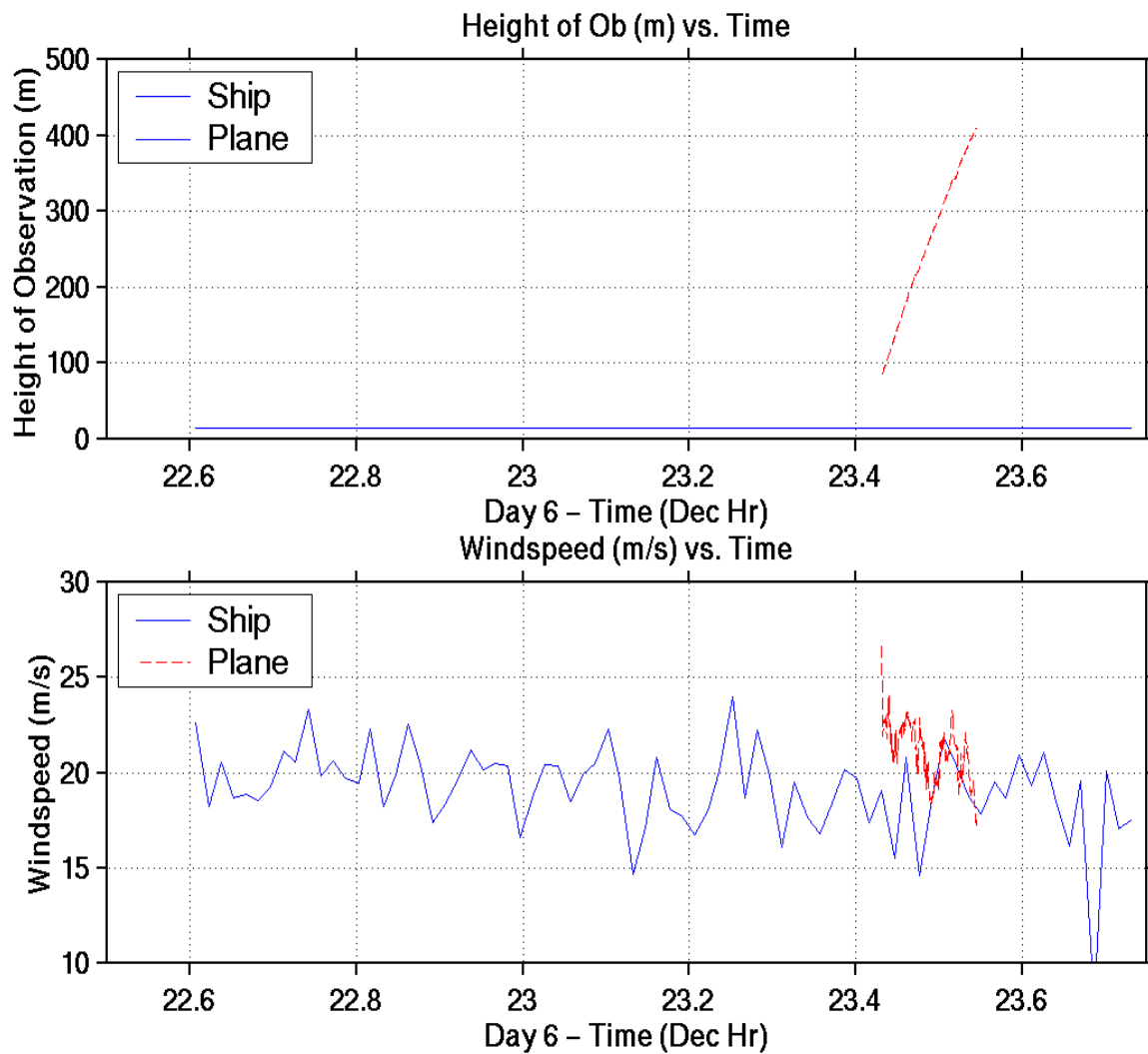


Figure 8

27 January 2003 Ship-measured and Aircraft-measured Wind Field

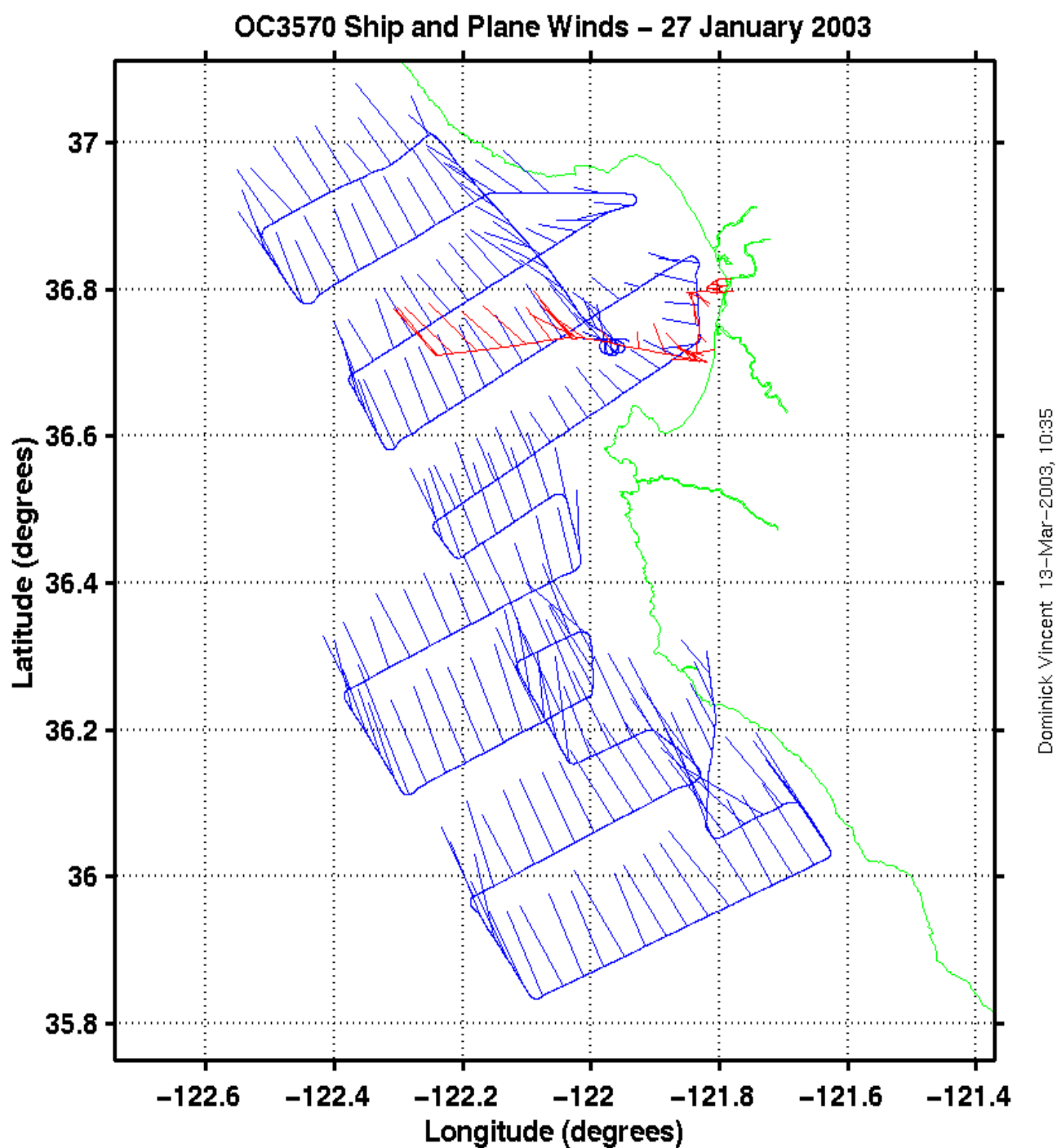


Figure 9

1 February 2003 Ship-measured and Aircraft-measured Wind Field

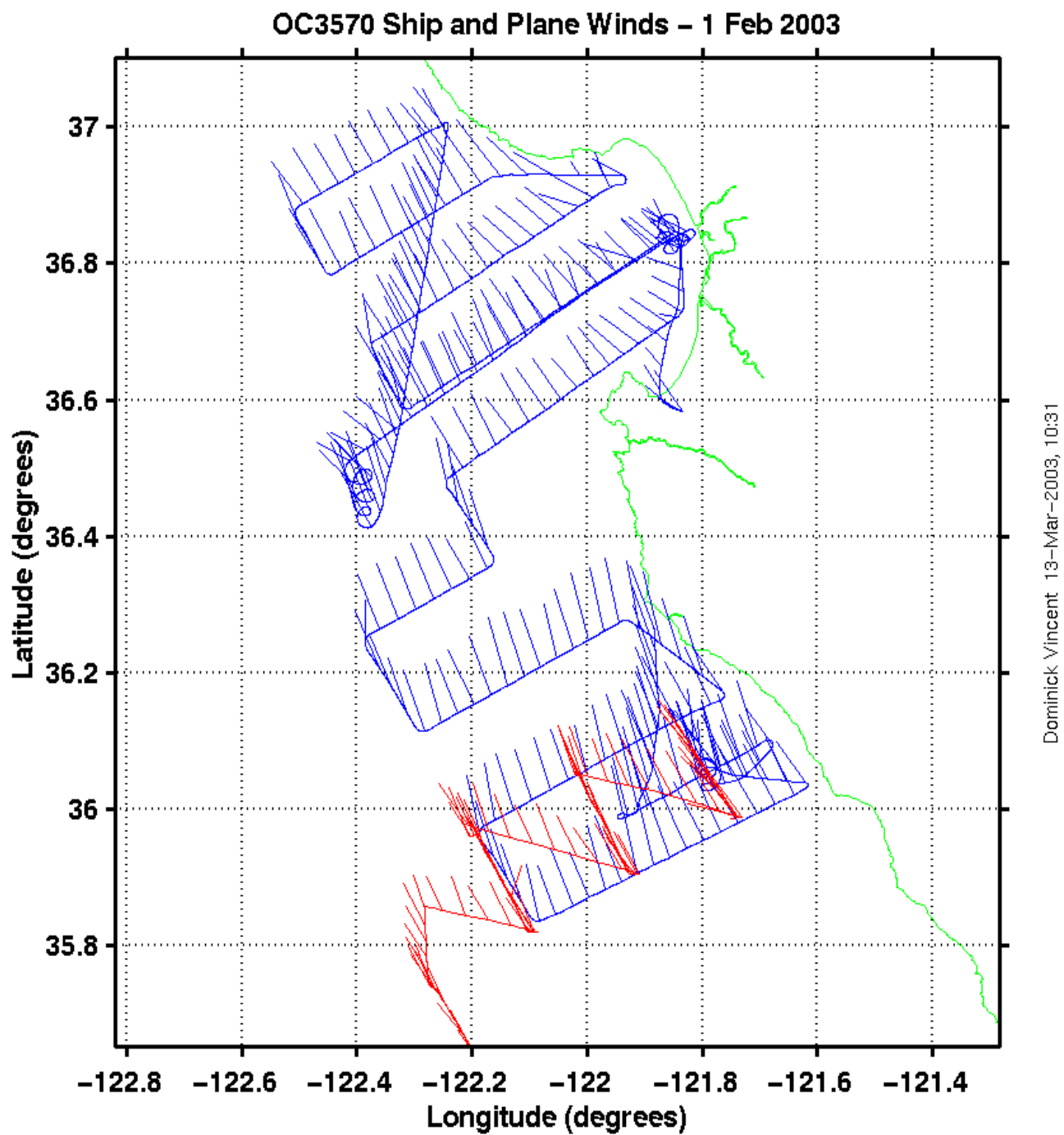


Figure 10

27 January 2003 Ship-measured and Aircraft-measured Wind Field - Zoom

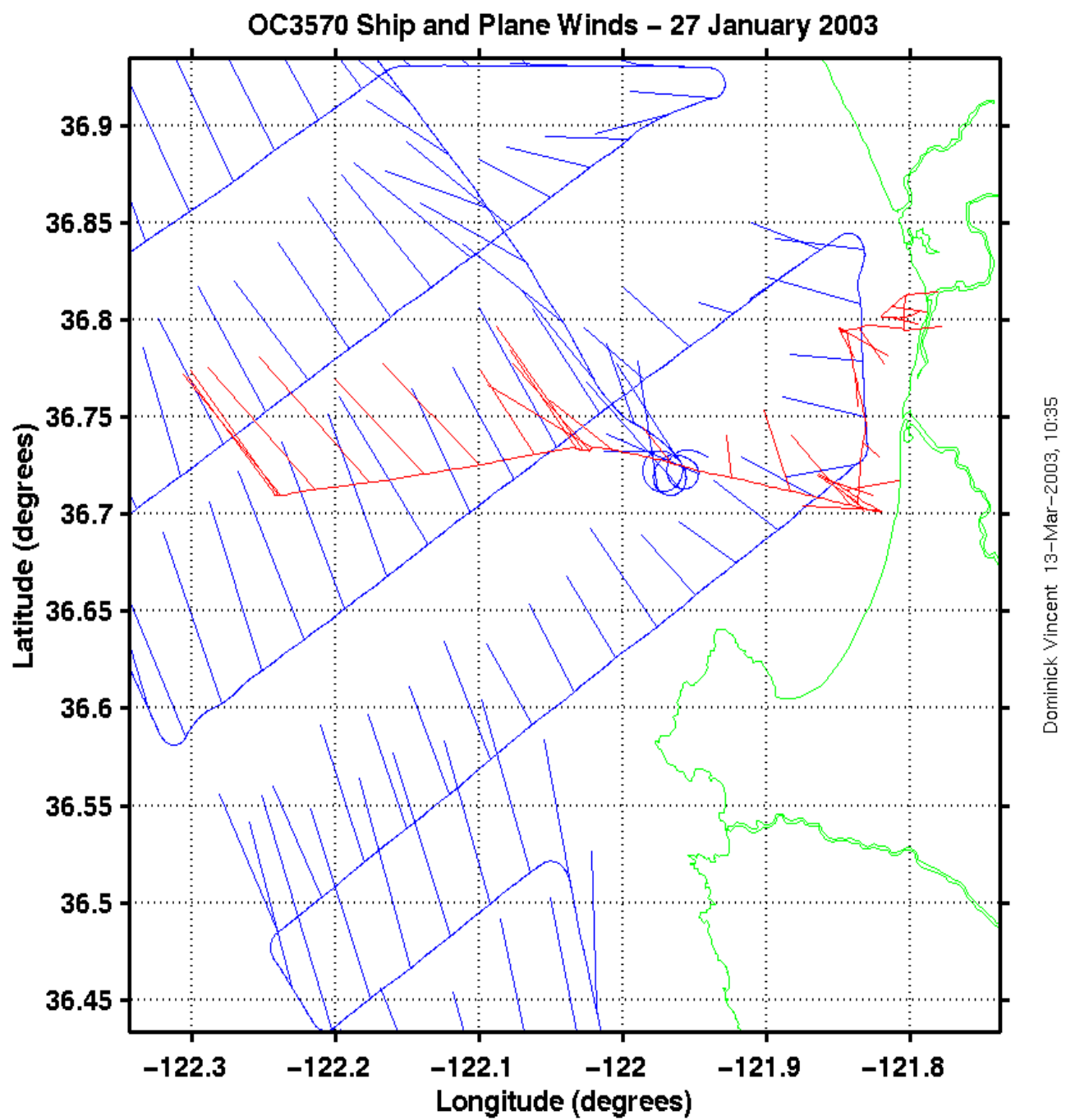


Figure 11

1 February 2003 Ship-measured and Aircraft-measured Wind Field - Zoom

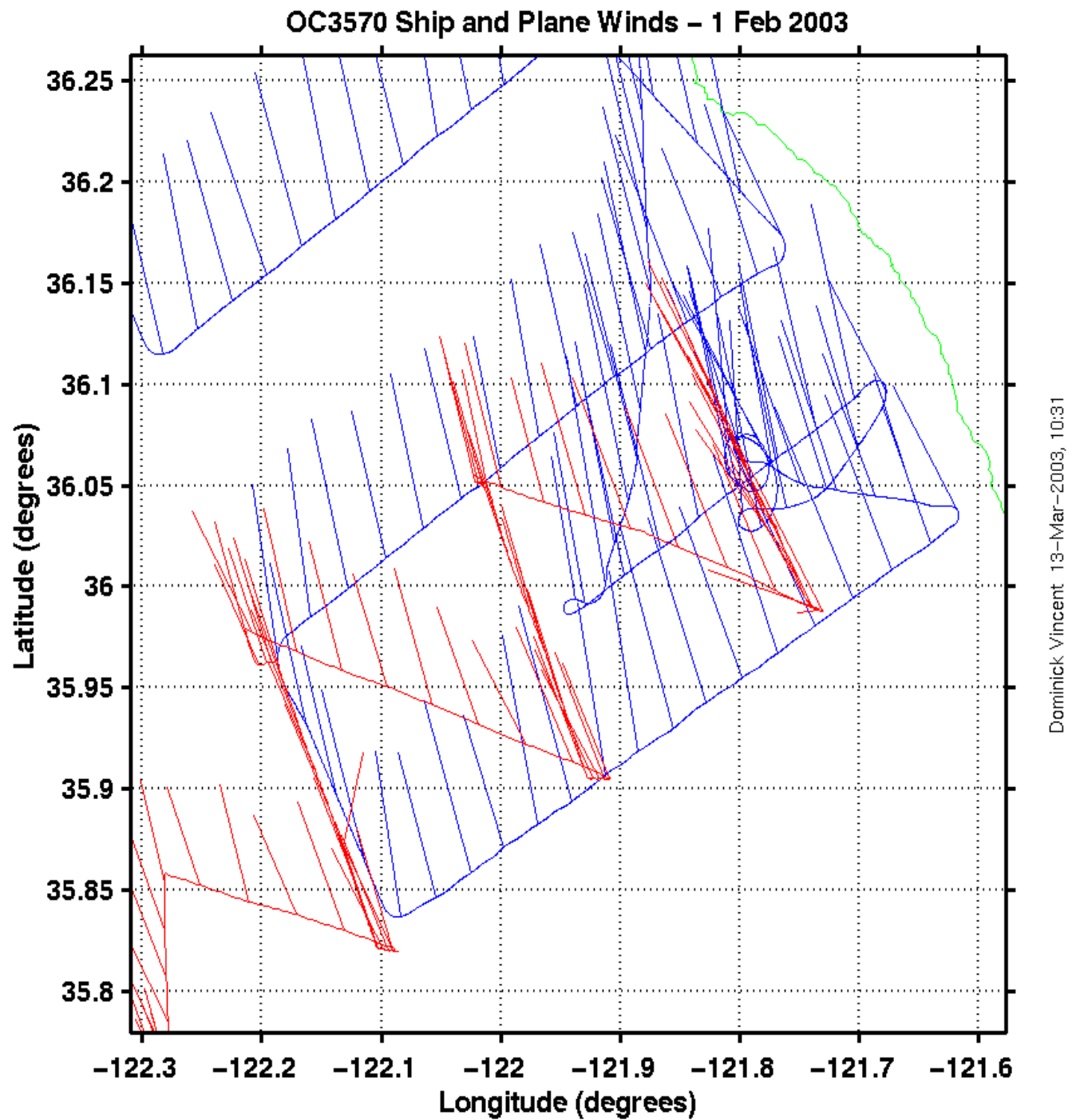


Figure 12

27 January 2003 Upper Air Sounding – R/V POINT SUR

R/V Pt Sur 36.71 N 121.84 W 27 JAN 03 20:11 GMT

03012719.cap

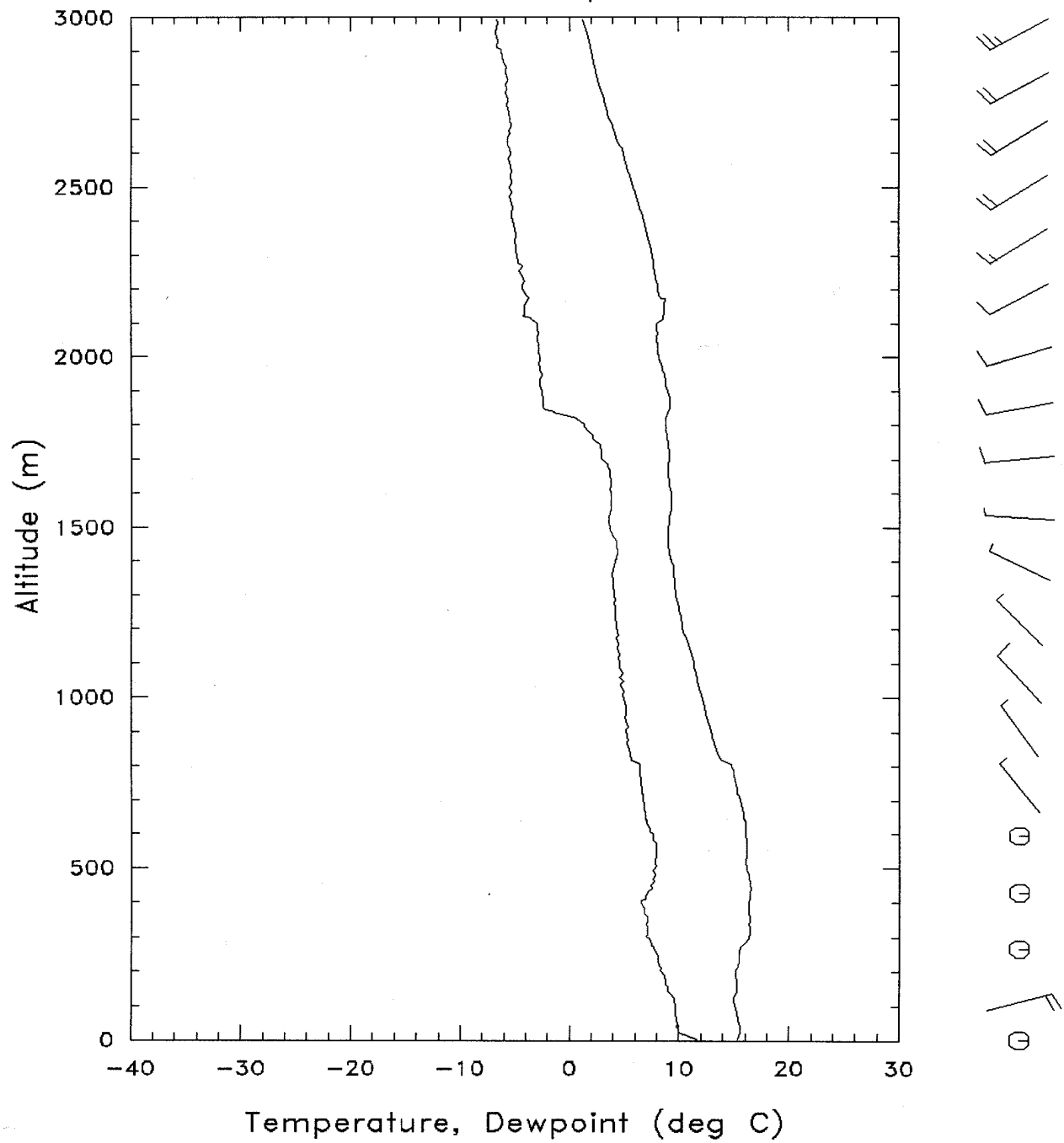


Figure 13

1 February 2003 Upper Air Sounding – R/V POINT SUR

R/V Pt Sur 36.02 N 121.76 W 1 FEB 03 22:48 GMT

03020122.cap

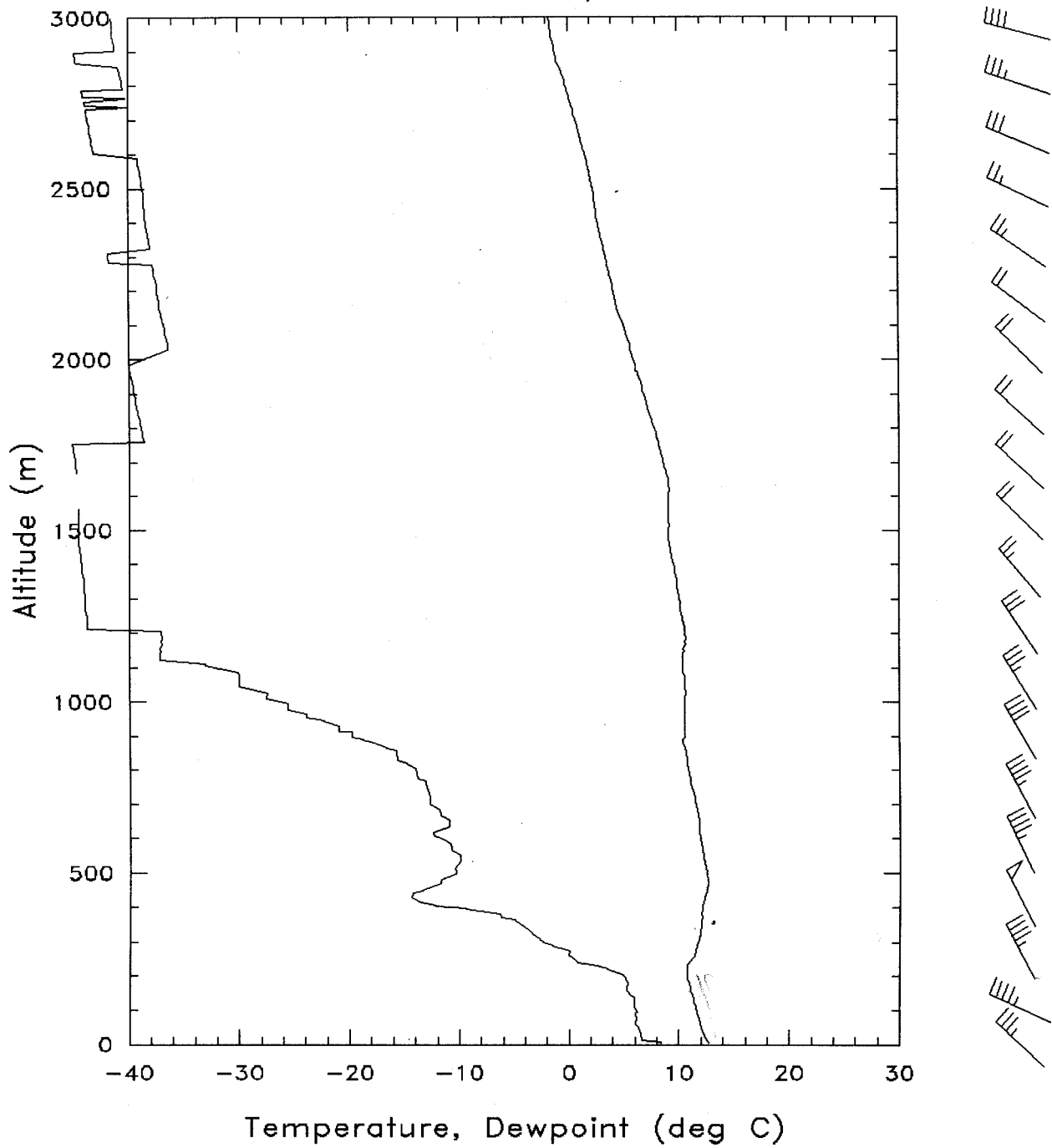


Figure 14

27 January 2003								
Input Parameters			10-Meter Normalized Parameters			Bulk Method Derived Surface Fluxes		
	Ship	Plane		Ship	Plane		Ship	Plane
Air Temp (C)	14.1	14.9	Temperature (C)	14.1	14.8	Sensible Heat Flux (W/m ²)	-2.3	-4.3
Pressure (mbar)	1018.7	1012.2	Potential Temp (K)	287.4	288.0	Latent Heat Flux (W/m ²)	3.0	20.9
Relative Humidity (%)	94.4	66.3	Wind Speed (m/s)	5.0	3.5	Total Heat Flux (W/m ²)	0.7	16.6
Sea Surface Temp (C)	13.8	13.6	Specific Humidity (g/kg)	9.4	7.4	Drag Coefficient	0.0010	0.0008
Wind Speed (m/s)	5.2	4.2				Wind Stress (N/m ²)	0.0304	0.0118
Height of Ob (m)	14	20.7						
1 February 2003								
Input Parameters			10-Meter Normalized Parameters			Bulk Method Derived Surface Fluxes		
	Ship	Plane		Ship	Plane		Ship	Plane
Air Temp (C)	12.9	12.4	Temperature (C)	13.0	13.0	Sensible Heat Flux (W/m ²)	5.2	-6.3
Pressure (mbar)	1015.6	985.8	Potential Temp (K)	286.2	286.3	Latent Heat Flux (W/m ²)	142.7	394.8
Relative Humidity (%)	77.7	39.9	Wind Speed (m/s)	18.7	22.0	Total Heat Flux (W/m ²)	147.9	388.5
Sea Surface Temp (C)	13.3	12.9	Specific Humidity (g/kg)	7.2	4.3	Drag Coefficient	0.0017	0.0019
Wind Speed (m/s)	19.3	26.9				Wind Stress (N/m ²)	0.7466	1.115
Height of Ob (m)	14	81						

Table 1

